



RESEARCH DEPARTMENT



REPORT

Low-frequency sound absorbers

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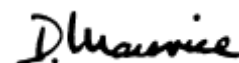
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A.N. Burd, B.Sc., F.Inst.P.

(PH-70)



Head of Research Department

LOW-FREQUENCY SOUND ABSORBERS

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LOW-FREQUENCY SOUND ABSORBERS

Summary

Membrane low-frequency absorbers have been used for many years in the BBC for the absorption of low-frequency sound. A variant of this type of absorber using a compound panel had some success, but careful choice of the size and shape was necessary to obtain the optimum performance.

Simplifications in the construction of perforated absorbers have led to a cheaper and more easily reproducible prefabricated form.

1. Introduction

The absorption of low-frequency sound energy has been a problem for many years. Middle and high frequencies are absorbed by many normal building materials to give empty-room reverberation characteristics that fall steadily towards the high frequencies. A slight rise of reverberation time at low frequencies in a studio may be acceptable and, according to some authorities, may be desirable. However, if this rise is too great, middle-frequency components are masked by lower-frequency sounds. The absence of binaural localisation in a monophonic broadcasting chain exaggerates the importance of indirect sounds and makes faults at low frequencies particularly noticeable.

The absorption of low-frequency sound is most effectively achieved by resonant systems. Helmholtz resonators, in which the mass of air in the neck of a rigid box resonates in conjunction with the stiffness of the large volume of air in the box, have been used to a limited extent in broadcasting studios¹ and are at present receiving renewed attention on account of their use in the Queen Elizabeth Hall, London.

Membrane absorbers, in which a membrane enclosing an air space vibrates against the spring stiffness of the air space, were developed within BBC Research Department before 1948²; they have been used in studios of all sizes with considerable success. The membranes are made from bitumenous roofing-felt which has excellent mechanical properties for this application. However, it suffers from disadvantages due to its poor mechanical strength, its unpleasing appearance and its obvious fire hazard qualities. The first two faults have been overcome by covers of fabric or perforated hardboard, but these have visual disadvantages. A bitumenous material is not an acceptable fire risk

in a studio to which the public has access. An efficient substitute has therefore been sought.

This report describes an alternative form of panel absorber which has found some application in studio acoustic treatment. An improvement in its performance was produced by changing the shape of the absorber.

Low-frequency sound absorption by means of perforated faced absorbers has also proved a worthwhile alternative acoustic treatment.

2. Panel absorbers

In order to determine the mechanical characteristics necessary for a material to be used in membrane absorbers, measurements of the mechanical properties of various materials, including roofing-felt, were made. A strip of the material was clamped at the ends and its resonance frequency and the bandwidth of the resonance were measured; the stiffness and the damping factor of the strip could then be determined. Measurements were made on roofing-felt, stuck to a strip of hardboard whose properties were already known. The properties of the roofing-felt could thus be determined, but it was also found that the combination of hardboard and roofing-felt possessed internal damping similar to that exhibited by the roofing-felt alone. Absorbers were therefore constructed of hardboard and roofing-felt, bonded together and mounted over an air space.

The tests on the prototype bonded hardboard and roofing-felt absorbers were carried out on individual units of 0.6 x 1.2 m frontal area arranged in groups of three in the reverberation room to form a standard divided-sample layout³; the total sample area was 9 m². The results

obtained for various depths of air space are shown in Fig. 1. These figures were obtained without any added resistive backing (porous material in the air space) and suggested that there was adequate resistance in the panel; the addition of damping material would be expected to broaden the peaks.

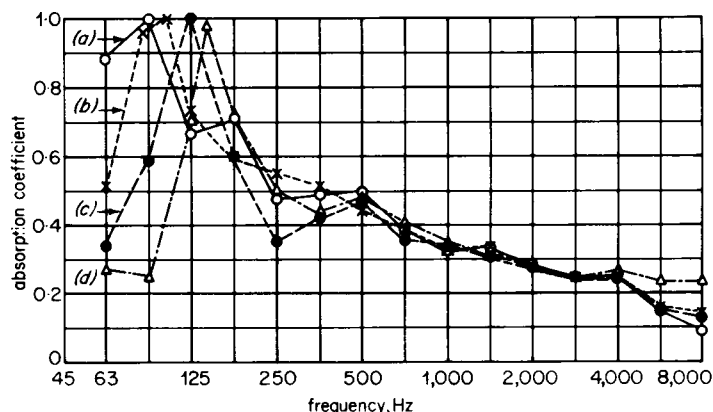


Fig. 1 - Absorption coefficients of bonded hardboard and roofing-felt absorbers: prototype measurements

- (a) 16.5 cm deep air space (b) 12.5 cm deep air space
(c) 10 cm deep air space (d) 7.5 cm deep air space

The construction of these absorbers went some way towards overcoming the faults which had limited the application of the simple membrane absorbers. The sheet of hardboard was smooth and could be painted, and the fire hazard could be substantially reduced by the use of flame-retardant finishes to the hardboard and the box enclosing the roofing-felt. In particular, only this type of absorber was acceptable to the G.L.C. fire authorities for use in television studios. However, some additional protection was requested and this was provided by mounting a layer of rockwool a small distance in front of the face of the absorber.

Of the eight major studios at Television Centre only one shows any tendency to rise in reverberation-time at low frequencies and this is within acceptable limits (35% rise at 63 Hz relative to the mean value over the range 500 – 2000 Hz). The remainder are either uniform with frequency or show a fall in reverberation-time at low frequencies.

However, unexplained rises in reverberation-times at low frequencies in certain sound studios caused doubts about the performance of these absorbers and these doubts were confirmed by measurements made on some of the production versions of the absorbers.

One of the early failures of this type of absorber was in a studio in East Anglia and some of the absorbers, with an area totalling 7.4 m², were returned for tests. The results, shown as curve (a) in Fig. 2, were disappointing when compared with the prototype measurements (Fig. 1). It was found, however, that over much of the area of the panels the roofing-felt was not adhering to the hardboard. Curve (b) shows the absorption characteristic of mass-produced absorbers as used in a television studio, tested in an echo room at Television Centre (Sample area; 12 m².

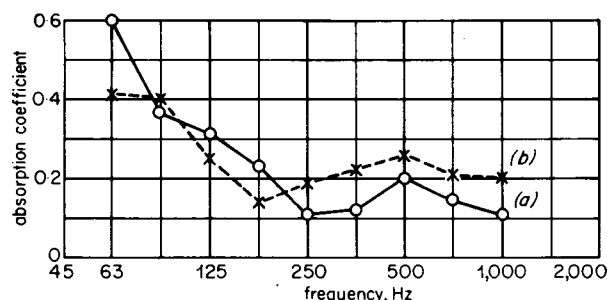


Fig. 2 - Absorption coefficients of bonded hardboard and roofing-felt absorbers:

- (a) East Anglia studio absorber 7.4 m² sample area
(b) Television studio absorber 12 m² sample area

Depth; 15 cm. Frontal area, 0.9 x 1.06 m with subdivided air space). The coefficients were much lower than those indicated by studio reverberation measurements and it seemed possible that the rockwool placed (in the studio) in front of the faces of the absorbers was necessary for additional resistive damping. As a consequence damping material has subsequently been specified for inclusion in all membrane absorbers.

Other possible variations in the construction or application of these absorbers have been studied and are reported briefly in the Appendix.

3. Modular shape of absorber

The possible influence of the size and shape of a panel absorber on its absorbing characteristics is known but not fully understood. Theoretically, for the greatest absorption, the absorber's radiation impedance (which varies with area) must be matched to its acoustic impedance and thus, for a particular membrane material, the absorber size should be selected to give the appropriate radiation resistance.

Measurements of the vibration amplitude of the membrane surface of a 1.2 x 0.6 m bonded absorber showed that, at the frequency at which the maximum absorption occurred, the panel vibration reached maxima at two points on the surface. Fig. 3(a) shows the general shape of the contours of constant acceleration magnitude on the surface, the two points of maximum acceleration vibrating in phase. The most likely mode for a panel excited by a (uniform) pressure field would appear to be combinations of first and third harmonics which might give rise to vibration such as that described. This is illustrated in Fig. 3(b).

It seemed probable that the frequency at which the radiation and acoustic impedances are complex conjugates, giving rise to maximum absorption, is higher than the fundamental mode of oscillation of a 1.2 x 0.6 m panel made from this material. The box and panel were therefore subdivided to form two 0.6 m square absorbers, each of which appeared to vibrate primarily in a fundamental mode at the frequency where maximum absorption was expected. The contours of acceleration amplitudes for this size of absorber are illustrated in Fig. 3(c).

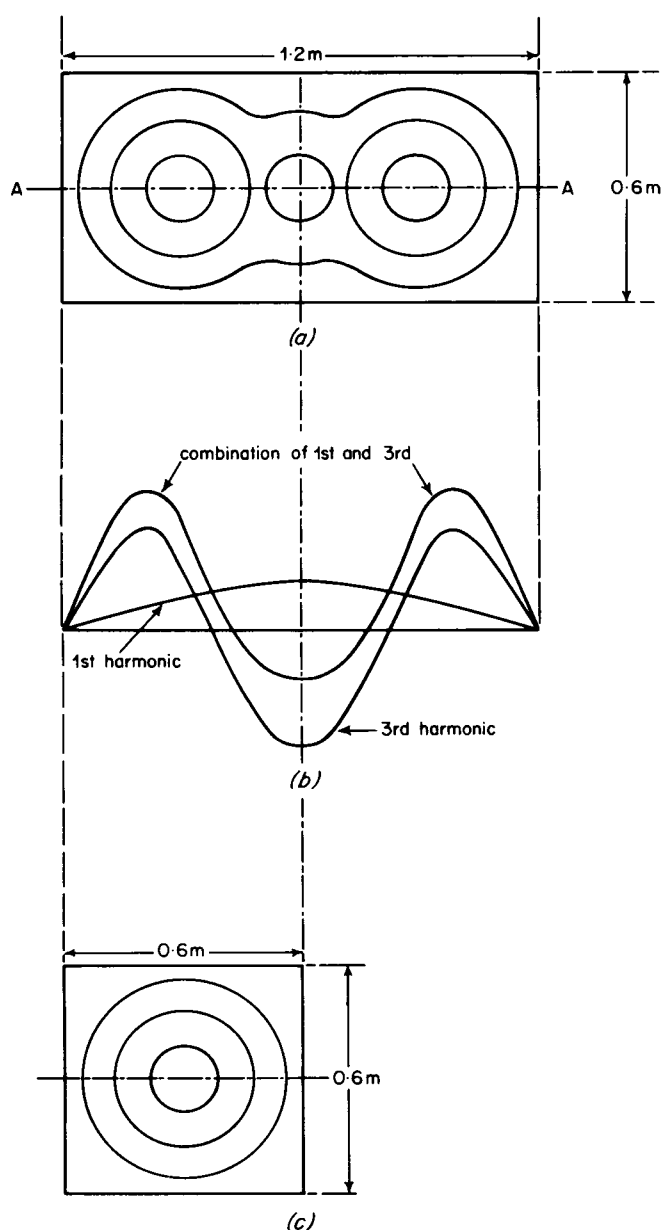


Fig. 3 - Vibration patterns of different modular sizes:
 (a) 1.2 x 0.6 m absorber excited at 63 Hz
 (b) Possible modes of vibration of 1.2 x 0.6 m absorber
 (c) 0.6 x 0.6 m absorber excited at 63 Hz

It has been shown that absorption coefficients can be derived from impedance measurements on samples of absorbers.⁴ For the 1.2 x 0.6 m sample the results derived in this way showed two prominent maxima; in the case of the 0.6 m square sample the second peak was displaced and considerably reduced in height. Reverberation room measurements, with a 4.5 m² sample of each type, largely confirmed the predictions of the impedance measurements. The results are shown in Fig. 4.

Fig. 4(a) shows the absorption coefficients for rectangular shaped absorbers and compares the results predicted from the measured impedance with those from reverberation room measurements.

Fig. 4(b) shows the similar results for the square absorber. The improvement in both the peak absorption

and the bandwidth resulting from the change of shape is apparent in the reverberation room measurements; the general form of the results is predicted by the impedance measurements.

4. Pre-fabricated absorbers

Absorbers for the treatment of studios have normally been constructed on site by the contractors. While a limited amount of prefabrication was possible, some types of absorbers for a group of studios being made in batches, full advantage could not be taken of factory methods of construction.

Recently the design and construction of a series of local broadcasting studios called for a supply of cheap absorbers which could be rapidly installed. The treatment used in the design was limited to acoustic tiles stuck to the ceiling, a carpet with underfelt on the floor and two types of modular absorber.

The design of these absorbers* is based on a simple type used in the early days of studio design. A layer of porous absorber material is mounted over a comparatively deep air space (15 – 20 cm) and proves to be an efficient use of absorbing material.⁵ If the air space behind the absorbing material is partitioned, improved absorption is found at low frequencies.

In the current design of absorber, the material is included in a wooden box the face of which is closed by a perforated hardboard. The partitioning supports the absorber material and the hardboard face retains it. The boxes are constructed with small brackets attached so that they can easily be fastened to battens on the studio wall.

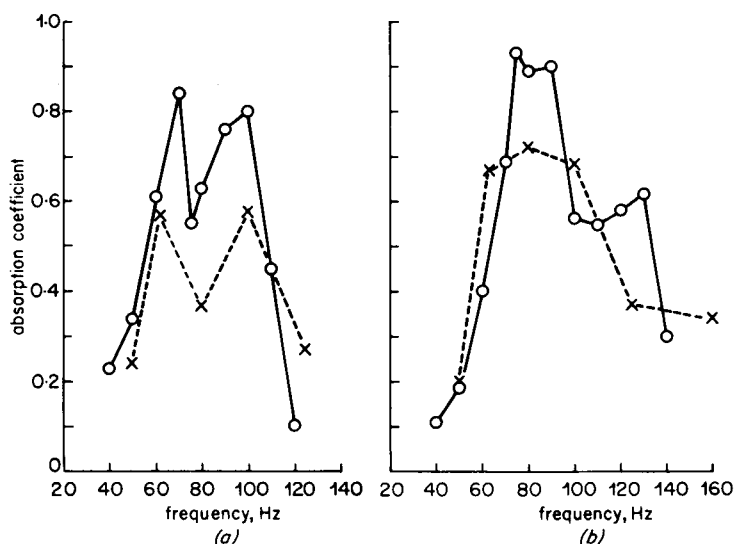


Fig. 4 - Absorption coefficient of bonded absorbers of different modular sizes: comparison between prediction and measurement

(a) 1.2 x 0.6 module (b) 0.6 m square module
 ○—○ predicted from impedance measurements
 ×---× reverberation room measurements

* by A. Brown, Acoustics Architect, BBC Architects and Civil Engineers Department.

Progressive modifications, particularly to the partitioning, have simplified and cheapened the construction with only a marginal reduction in the efficiency of absorption. The current range of absorbers use a cardboard 'egg-boxing' of the appropriate depth to divide the air space. The measured absorption coefficients for two different types of perforated hardboard facing are shown in Fig. 5.

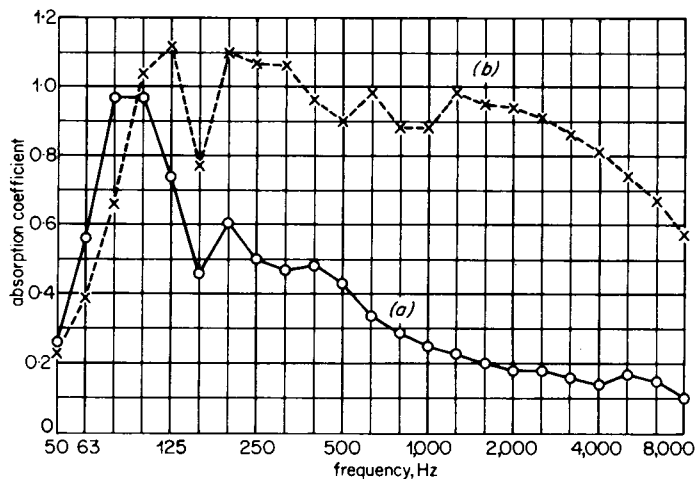


Fig. 5 - Pre-fabricated absorbers having cardboard partitioning at 10 cm centres

(a) 0.5% perforated covers (b) 25% perforated covers

Using these two types of modular absorber, together with the other absorbing materials mentioned previously, studios having an acceptable reverberation time-frequency characteristic can be produced. Panel absorbers will probably, therefore, be used less, at least for the present.

5. Conclusions

Panel absorbers, having a surface of bonded hardboard and roofing-felt, were developed to overcome aesthetic and fire hazard objections to roofing-felt absorbers. Their absorption can be improved by the selection of a panel size and shape whose natural resonance frequency is compatible with their expected peak absorption frequency.

Improvements in perforated porous absorbers have reduced the use of panel absorbers. The low price and ease of fixing of these should make them the first choice for most future work.

6. References

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APPENDIX

Absorber Characteristics

Impedance measurements

It was obviously not possible to recall 10 m² of low-frequency absorbers from each of several studios when doubts about their behaviour arose. A technique was therefore developed for determining the acoustic impedance of membrane-type bass absorbers *in situ*.⁵ From the measured impedance the absorption coefficients could be calculated and excellent agreement was shown with measurements in an orthodox standing wave tube. It has been further suggested that, where measurements are taken in a room of short reverberation time (say, 0.3 secs), a random incidence impedance is obtained.

Clearly this technique permits measurements to be made on a single sample of an absorber; very little material is thus required for evaluation. In particular, the effects of minor constructional changes can thus be examined. Obviously the sample tested must be typical of the material it represents.

Reverberation-room tests have been carried out on a few samples of different material whose impedances have also been determined. Figs. 6(a) and 6(b) show two cases where impedance measurements and reverberation-room results can be compared.

Fig. 6(a) was obtained from a membrane absorber consisting of two layers of bituminous roofing-felt stretched over a 15 cm air space; a damping layer of 25 mm of low-density rockwool was incorporated a short distance behind the membrane. The impedance measurements give a curve which is sharper than that resulting from the random-incidence absorption measurements in the reverberation room. Fig. 6(b) was obtained for a membrane of 28 swg sheet steel to which three layers of damping material were applied.

The agreement was considered adequate for predictions, in these and similar cases, on the basis of impedance measurements alone.

II

Enclosure construction

It has always been considered to be good building practice to seal all air spaces in the absorber boxes. A mastic sealing gun is run round all internal corners and the membrane is fixed with adhesive and pinned. But, for the experimental boxes and membranes used in the development of bass absorbers, the type of membrane and its position together with the type, thickness and position of resistive damping treatment were changed almost daily, and the boxes developed a considerable number of leaks.

The influence of these leaks was explored by calculating from the measured impedance values the effect on a membrane absorber as holes and slots were cut in the box. Fig. 7 shows the effects on the absorption obtained from a particular absorber as a long saw cut was opened in one side of the box. The effect is only slight, so that subsequently extreme precautions have not been taken in sealing absorber boxes. The result must obviously depend on the

stiffness of the membrane; an absorber which relies entirely on the stiffness of the enclosed air would be expected to show more effect than the panel type.

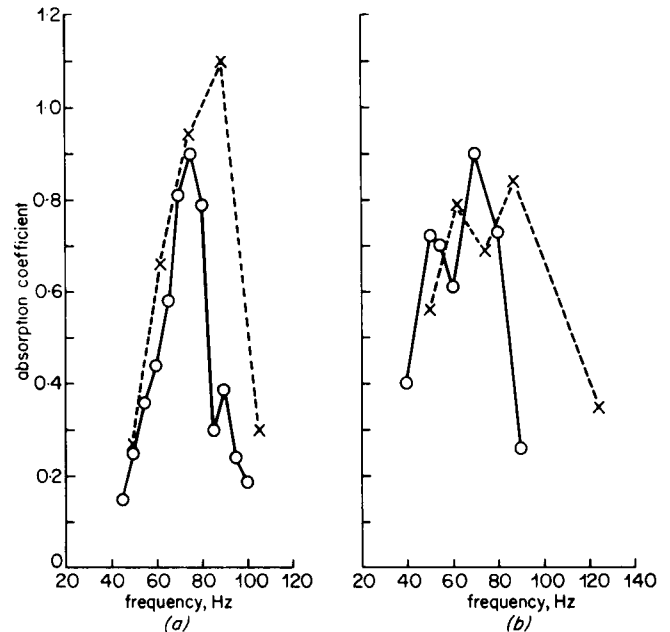


Fig. 6 - Comparison of absorption coefficients predicted by impedance measurement with those measured in a reverberation room

(a) Bituminous roofing-felt membrane
(b) Damped steel membrane

○—○ predicted from impedance measurements
x---x reverberation room measurements

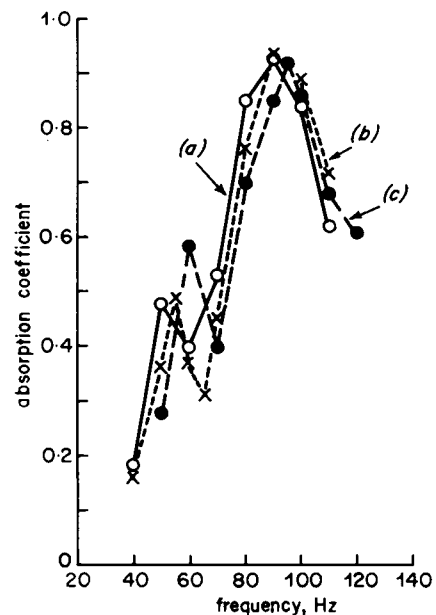


Fig. 7 - Effect of opening a saw cut in the side of an absorber box. (Absorption coefficients predicted from impedance measurements)

○—○ No saw cut x---x 30 cm saw cut
●—● 80 cm saw cut

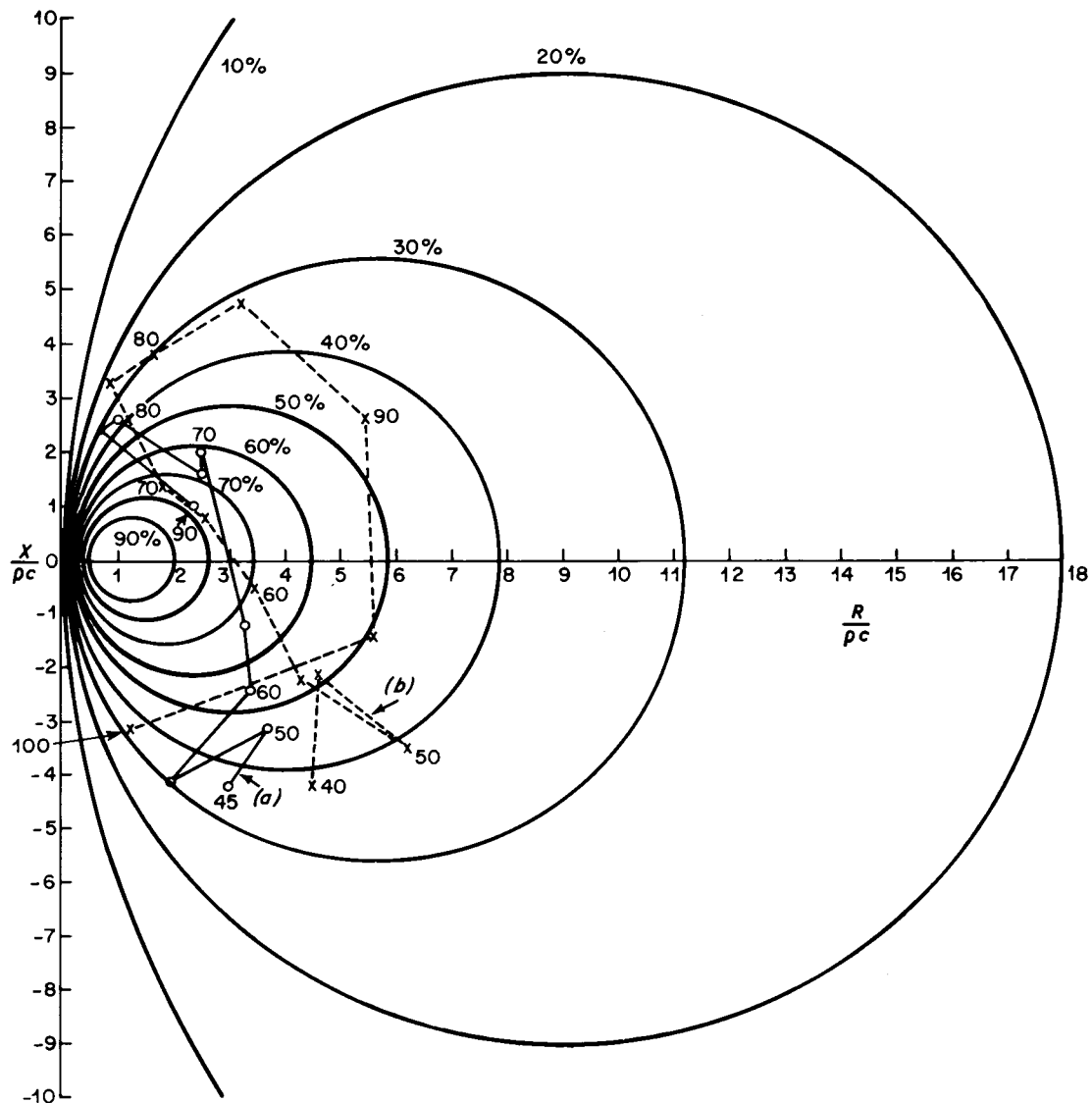


Fig. 8 - Acoustic impedance locus charts of studio absorbers (measured frequencies are marked at 10 Hz intervals)

(a) ○ — ○ Studio A (b) x - - - x Studio B

III

Influence of adhesives

After the initial development of bonded absorbers, possible methods of sticking hardboard to roofing-felt were investigated using small samples. A water-based poly-vinyl-acetate adhesive was selected which was cheap to apply and produced a satisfactory bond. The full scale reverberation-room tests were made with sheets stuck with this adhesive and it was subsequently specified for the construction of the units. During the studio investigations it was found that at least five adhesives were in use.

A non-hardening mastic manufactured by the makers of the bitumenous roofing-felt, and therefore thought to be compatible with the roofing-felt, was allowed as an alternative to the poly-vinyl-acetate adhesive, but other adhesives were discontinued. The use of the suitable adhesive appeared to be necessary but not sufficient for good

performance.

IV

Studio measurements

The impedance technique was required for measurements on absorbers *in situ*. Two studios are considered here; in Studio A, the low-frequency reverberation time was as expected from calculation; in Studio B, the low-frequency reverberation time rose to twice the design figure. The measured impedance diagrams obtained by inserting a probe microphone behind the bonded hardboard and roofing-felt membrane while irradiating it with pure tone are shown in Fig. 8 as Curves *a* and *b* for Studios A and B respectively. These curves differed so much that the units were dismantled; those in Studio A bore little relation to the specification for such absorbers. Framing had been included at roughly the dimensions specified for the

absorber but no sub-divisions existed and the airspace opened directly into skirting and ceiling voids. But the absorbers whose behaviour was in doubt were apparently constructed correctly.

While this technique has proved satisfactory in laboratory investigations it would appear that its use in studio measurements should be treated with considerable caution.